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MINING METHODS AND COSTS OF THE SILVER KING COALITION MINES CO., PARK CITY, UTAH

BY

M. J. DAILEY

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By M. J. Dailey[2]

INTRODUCTION

This paper is one of a series being prepared by the United States Bureau of Mines on mining practices, methods, and costs in the various mining districts of the United States.

The property of the Silver King Coalition Mines Co. is situated in the western part of the Park City mining district, Utah, about 1½ miles southwest of the town of Park City. The elevation at the collar of the main shaft is 8,137 feet above sea-level.

Park City, a town of about 4,500 population, is served by two railroads. A branch of the Denver & Rio Grande Western Railroad connects Park City with Salt Lake City, 32 miles westward, and a branch of the Union Pacific Railroad connects the town with the main line of that railroad at Echo Junction, east of Ogden.

In 1929 the Silver King mine produced about 180,000 tons of lead-silver-zinc ore, most of which was treated by flotation in the company's concentrator.

ACKNOWLEDGMENTS

The author acknowledges the assistance of Wm. O. Vanderburg, associate mining engineer, United States Bureau of Mines, and of M. G. Heitzman and C. J. O'Neill, general mine superintendent and mine foreman, respectively, of the Silver King Coalition Mines Co., for their assistance in the preparation of this paper.

HISTORY

The Park City district, famous for the richness, size, and continuity of its silver-lead ore deposits, was a farming community first and a mining camp afterward. The pioneers who in 1853 settled the fertile valley called Parley's Park looked on the area as one valuable chiefly for its rich land, abundant pasturage, and thick

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6371."

2 One of the consulting engineers, U. S. Bureau of Mines, and general manager, Silver King Coalition Mines Co.

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groves of aspen, pine, and fir. Erosion had rounded off the mountains and effectually concealed the vast mineral wealth lying below the surface. The principal outcrops--the Ontario in Ontario Canyon, the Crescent on Crescent Hill, and the Woodside in Woodside Gulch--were merely small knobs of high-grade lead-silver ores, which for years eluded the search of prospectors.

The first mining claim in the district was the Green Monster, located in 1869. In 1870 the Walker and Webster mine was located. Two years later Rector Steen discovered the Ontario mine, an event that was to determine the future trend of industrial operations in the Park City district, stimulating large-scale mining operations which have flourished continuously for 58 years.

With the discovery of the Ontario fissure system and with its value proved, other ore-bearing veins were soon found which made the district world famous. Driving the Ontario tunnel (1888-1894) a distance of 15,000 feet and the completion of other drain tunnels have greatly facilitated mining in the district by lowering the water level.

Rich float found in the vicinity of Woodside Gulch led to the discovery by Fred Willmen and John Farish, in 1888, of the outcrop of the vein system now composing the ore bodies of the Silver King Coalition Mines Co. The present holdings of this company are made up of the claims, acreage, and interests of a number of smaller companies which started operations independently but have been acquired by purchase or consolidation. The company now owns property embracing about 4,300 acres, with more than 200 miles of underground workings.

GEOLOGY AND ORE DEPOSITS

According to the United States Geological Survey[3] the sediments of the Park City are limestones, sandstones, quartzites, and shales of Carboniferous and Triassic age. The more important of these from the point of view of ore deposits are the Park City limestone of upper Carboniferous age, and the Thaynes formation, comprising limestones, sandstones, and shales of Triassic age. The strata have been arched, forming part of the Park City anticline which has been broken by many faults. These sediments were intruded by diorite and diorite porphyry magmas which metamorphosed them and caused the deposition of metallic sulphides. Subsequent fracturing in a northeast-southwest direction occurred, and permitted renewed deposition of sulphides. Further faulting in a northwest-southeast direction presumably gave access of surface waters to the primary ore bodies causing oxidation of the sulphides. This faulting also caused some displacement of the ore bodies.

Ore deposits in the Silver King Coalition Mines property are of two kinds: Lode deposits and bedded replacement deposits. The mineralization is associated with fissures having a northeast-southwest strike that carry lode ores in the quartzite as well as in the limestone. The most productive formations are the Park City and the Thaynes. In these formations are found the bedded stopes. While replacement ores are restricted to certain members of the two formations occurring at

3 Boutwell, J. M., Geology and Ore Deposits of the Park City District, Utah: U. S. Geol. Survey Prof. Paper 77, 1912.

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different horizons, the most valuable and productive deposit occurs in a limestone bed in the Park City formation about 100 feet above the Weber quartzite. Another very productive horizon is on the contact of the Weber quartzite and the Park City limestone.

Bedded or replacement deposits as a rule are lenticular in outline. The margins are irregularly lobed, some of the lobes or arms extending hundreds of feet in distance from the main deposits. Some of the bedded deposits have been continuously productive for more than 10,000 feet along their strike, with no indications of a decrease either in metal content or the dimensions of the ore deposit.

Lode deposits are found in fissures that appear to be the channels through which the mineralizing solutions circulated and formed the replacement deposits in the limestone beds. Deposits of this character lie along a continuous, master-fractured zone rather than in a large number of small fissures.

The ores carry lead, zinc, silver, gold, and in some places copper. Metallic content of the ore in many stopes in the property has increased with depth. The lodes being worked at present consist of disseminated seams with fair-sized bunches of rich sulphide ore occurring in the fracture zones. In general, the fracture zones are well-defined and persistent. Production of the lode deposits is estimated as totaling 5 per cent of the total output of the Silver King Coalition Mines; the remaining 95 per cent comes from bedded replacement deposits.

Ore minerals at the Silver King Coalition Mines consist of galena, pyrite, sphalerite, tetrahedrite and their oxidized products. Gangue materials are country rock, quartz, chert, calcite, fluorite, and rhodochrosite.

PROSPECTING AND EXPLORATION

In the past a small amount of diamond drilling has been done - principally, however, to secure geologic information. Because of the irregular nature of the replacement ore bodies, diamond drilling fails to yield conclusive data.

Geologic factors affecting the ore deposits have been carefully studied and are well established. The principal method of prospecting consists of drifting in the quartzite beneath the Park City formation and, wherever practicable, upon mineralized fissures parallel to the strike of the ore bodies. By this procedure small stringers of sulphide ore are often found. By raising on such stringers into the ore-bearing members of the formation, ore bodies may be opened and blocked out ready for mining. Advantages of prospecting in this manner are: (1) Ore bodies are more economically developed and stoped by way of drifts underneath them. (2) The cost of drift maintenance in the quartzite is less than in limestone or ore. (3) Commercial lode deposits are found in the quartzite which might otherwise have been overlooked.

Another method of prospecting consists of following the ore downward by means of small winzes, or laterally by drifts along the contact or in the favorable limestone beds. From the information thus gained, haulage and working drifts can be extended and most advantageously placed for stoping the ore.

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DEVELOPMENT

The Silver King mine is served by one vertical main hoisting shaft, five vertical auxiliary underground shafts, and two drain tunnels. One of the latter, the Alliance tunnel, connects with the main shaft 500 feet below the surface and the other, the Silver King Consolidated, connects with the shaft 1,300 feet below the surface. From the Alliance tunnel, 9,600 feet from the portal and 1,400 feet below the surface, a three-compartment shaft has been sunk 800 feet to the 1300 level, with workings on the 600, 700, 900, 1100, and 1300 levels. This is known as the Silver Hill section. Similarly a three-compartment shaft has been sunk from the level of the Silver King Consolidated tunnel to the equivalent of the 1750 level of the Silver King Coalition Mines Co.'s main shaft. This interior shaft is in a crosscut 600 feet easterly from the main adit of a point 10,570 feet from the portal, and its collar is 1,650 feet vertically below the surface. This is the West End shaft, having workings of the 1500, 1600, and 1700 levels.

The Silver King property is so extensive that without these underground shafts long crosscuts would have to be run from the main shaft to ore deposits on each level. The alternative of sinking the auxiliary shafts from the surface would be uneconomical because of the rugged nature of the ground and the great depth of the ore bodies. By sinking shallow shafts close to the ore deposits and transferring the ore, development costs and capital investment have been kept at a minimum.

The main shaft has three compartments, two for hoisting which are 4½ feet by 5 feet in section, and a manway 2½ feet by 5 feet. Shaft sets are of 10 by 10 inch Oregon fir placed on 5-foot centers and lagged outside with 2-inch plank (fig. 1). The guides are of Oregon pine dressed to 3¾ by 4¾ inches, 20 feet in length and held in place by lag screws countersunk in the face of the guides.

The auxiliary underground shafts usually have three compartments; the hoisting department is of standard dimensions.

To determine the extent and course of the ore bodies, winzes are frequently driven on the dip of the ore bodies, which averages 20°. These winzes are driven 7 by 11 feet in section and are timbered with unframed stringer sets. Track is placed usually at one side so that if the ground becomes heavy additional posts can be placed in the center. The broken rock from sinking is hoisted in small skips.

Drifts and crosscuts for use as main haulageways are 6 by 8 feet in section and are timbered where necessary with the standard drift set shown in Figure 2. Sets are placed on 5-foot centers.

Raises for ore passes and for transferring supplies to the stopes have either two or three compartments and are timbered with unframed stringer sets of 8 by 8 inch timber. The caps are usually 5 feet long and the posts 4 feet 4 inches. Lagging consists of 2-inch plank placed lengthwise of the raise. Each compartment is 3 by 4 feet in the clear; one compartment is used for a manway and for transferring supplies. In a three-compartment raise the manway is in the center. Raises are generally driven at an angle of 70°. The ore has a tendency to stick in the chutes, and consequently it has been found that much time is saved in tramming if two compartments are available for ore passes.

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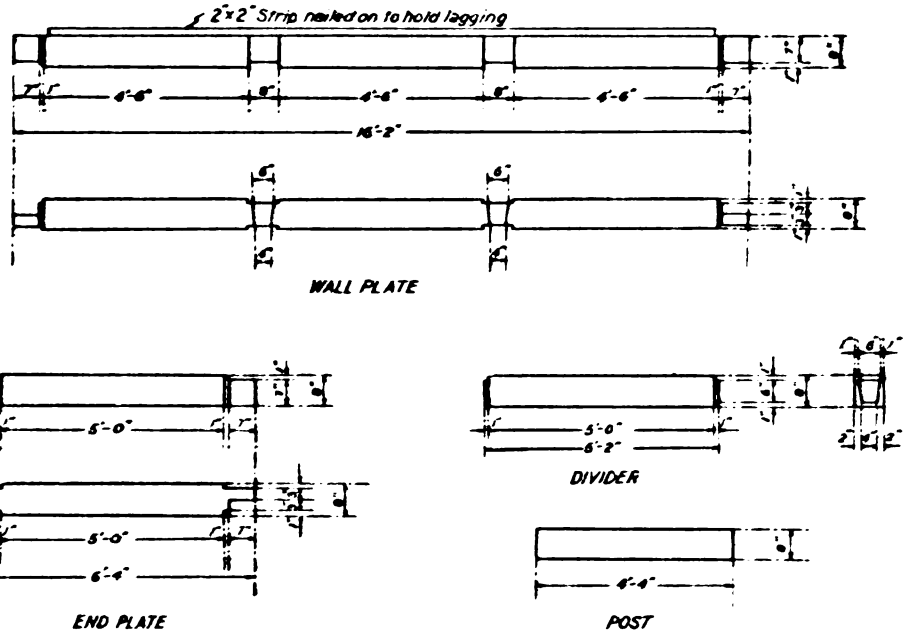

Figure 1.-Details of timber for 3 compartment shaft set.

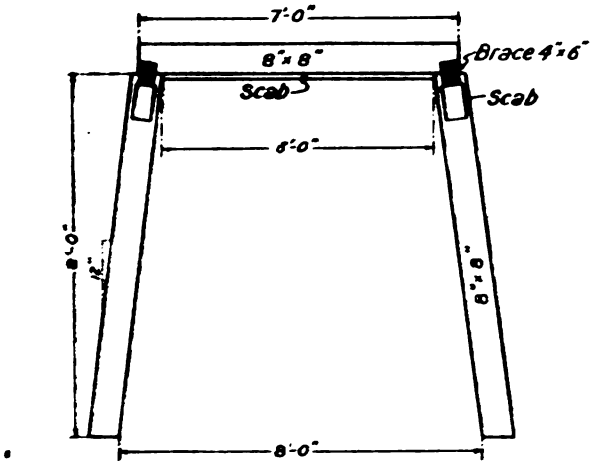

Figure 2.-Drift set.

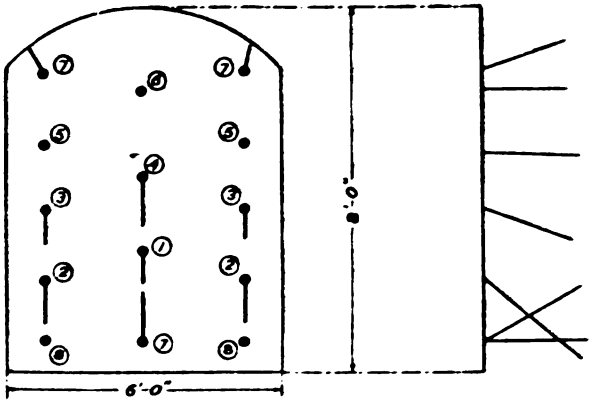

Figure 3.-Standard drift

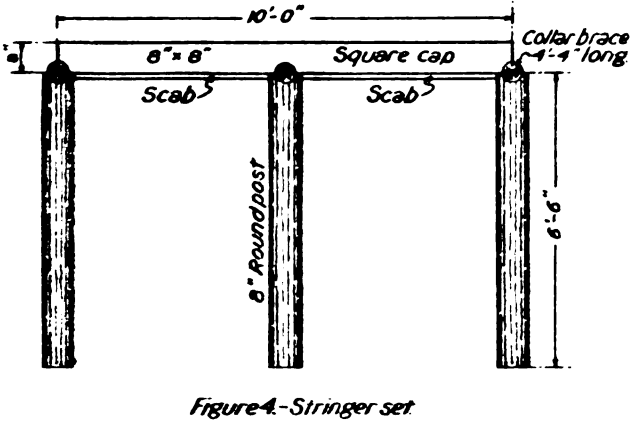

Figure 4.-Stringer set.

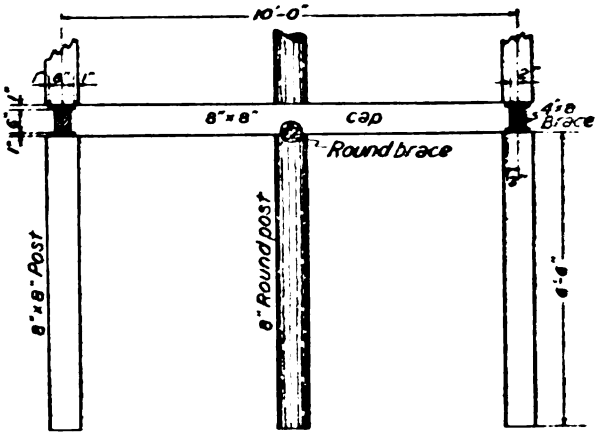

Figure 5.-Silver Hill framed set.

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Standard rounds for driving raises, crosscuts and drifts are shown in Figure 3. In raising and stoping, wet stoper drills are used with 1 and 1¼ inch octagonal steel. For drifting and crosscutting, Leyner machines are used with 1-1/8-inch hollow steel, and for shaft-sinking, jackhammers with 1-inch and 7/8-inch hollow hexagonal steel. The bits are of the usual cross type, with a double taper on the Leyner steel and a single taper on the stoper and jackhammer steel. The gage of bits is 2¼ inches for starters and 1/8 inch less for each succeeding size. Gelatin dynamite of 35 and 50 per cent strength is used for blasting.

STOPING

Practically all stoping is by overhand methods. In the Silver King section the type of stringer sets shown in Figure 4 is used to support the walls. These consist of unframed 8 by 8 inch caps 10 feet long supported on three round posts 8 to 10 inches in diameter and 6 feet, 6 inches long. Sometimes 8 by 8 inch square posts are used. Round girts 4 feet, 4 inches long are either spiked to the posts and caps or held in position by small blocks nailed to the post under the ends of the girts. In the larger stopes portions are filled with waste to support the hanging wall as stoping advances. In this case all available timbers are taken out before filling so that they can be used again.

In the Silver Hill section where the ground is heavier and the timbers are subjected to greater pressure the stringer sets are framed as shown in Figure 5. The posts and caps consist of 8 by 8 inch and the girts of 4 by 8 inch timbers. In mining the flat, heavy ore bodies where it is not practicable to advance the stope as one continuous face the ore body is mined in sections about 50 feet wide and supported on timbers. The length of such a section depends on the condition of the overhanging walls.

Around the edges of the ore bodies where the thickness is less and less support is required, 8 and 10 inch round stulls are placed at irregular intervals. Headboard of varying sizes and thickness are placed on the stulls.

As few holes as possible are drilled and blasted in the ore in order to save powder and to prevent shattering the walls and diluting the ore with waste. In some cases a single hole is all that is required to break tons of ore.

The broken ore is moved down the dip of the stope by hand-shoveling, wheelbarrows, or cars. Sublevels are driven underneath and in the stopes for economical transportation of the ore. Some attempts have been made to use "slushers", and also to use a mechanical shovel, but these were unsuccessful.

Between 15 and 20 per cent of the material broken in the stopes is sorted out as waste. This is done underground and the waste is returned to the stopes for fill. In the event that the waste thus obtained is not enough to fill a stope, waste drifts and raises are driven in places that have merit as prospects or ventilation or haulage openings. Such drifts are 5 by 8 feet in section, and are run close to the section of stopes to be filled. To avoid loss of ore that may be scattered in the fill when blasting, all stoping operations are abandoned while filling is being done.

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After a section of stope has been mined out, and before filling, the footwall is swept clean. This is done with wire brooms and by experienced men. The footwall is carefully inspected for small bunches or stringers of ore that may have been left. These often lead to finding profitable bunches of ore extending into the walls. So thoroughly is the cleaning done that after a stope has been swept it is difficult to see what the nature of the ore was.

The ore is drawn off through chutes into one-ton cars and trammed either by hand or motor to the nearest gathering switch. The chutes are made of 2-inch plank with wooden control gates sliding in cleats nailed to the chute sides. The floor of the chutes or storage boxes has a pitch of 55°.

A record is kept of the metal production of each stope. The shift bosses keep a record of the cars drawn from each stope, from which tonnages are calculated semimonthly. Grab samples are taken from all cars from each stope for assay. These are found to run about 2 per cent higher than the samples taken by the mechanical samplers on the surface. Estimates of tonnages and the metallic content of the ore are adjusted to agree with the figures based on automatic weighing and mechanical sampling at the head of the mill. By this means it is possible to determine fairly accurately the tonnage and value of ore taken from each stope, and also to calculate profit or loss at any time during the year while operations are being carried on.

Natural conditions in the Silver King Coalition Mines properties combine to aid mining. The area of ore-bearing formations is so large that production comes from a large number of places at the same time. The company therefore does not have to depend on any single stope for maintenance of uniform production. Development is never allowed to lag behind production. At present not more than 50 per cent of the faces of commercial ore in the property are in active operation.

In practically all of the ore mined there is enough zinc to make a profitable zinc product, which can be separated from the lead concentrates by flotation. Lower milling costs, better metal recoveries, production of a higher-grade shipping product, elimination of selective mining, and the fact that all ores mined are sulphide ores, enable the company to work at a profit low-grade ores that previously could not be mined.

UNDERGROUND HAULAGE

Track in the main haulageways consists of 30-pound rails laid on 4 by 6 inch ties, 32 inches long and spaced 2 feet apart. Sixteen or 20-pound rails are used in side drifts and crosscuts. Track gage throughout is 18 inches, and the average grade is one-half of 1 per cent.

Mine cars are of the end-dump box type (fig. 6). The body is 24 inches deep, 28 inches wide, and 44 inches long, with a capacity of 17 cubic feet or from 1,800 to 2,400 pounds of ore, depending on its character. The weight of the car is about 1,100 pounds. The wheels are 12 inches in diameter, with either ball or roller bearings. The body is mounted on a turntable so that it may be dumped at right angles to the track if desired.

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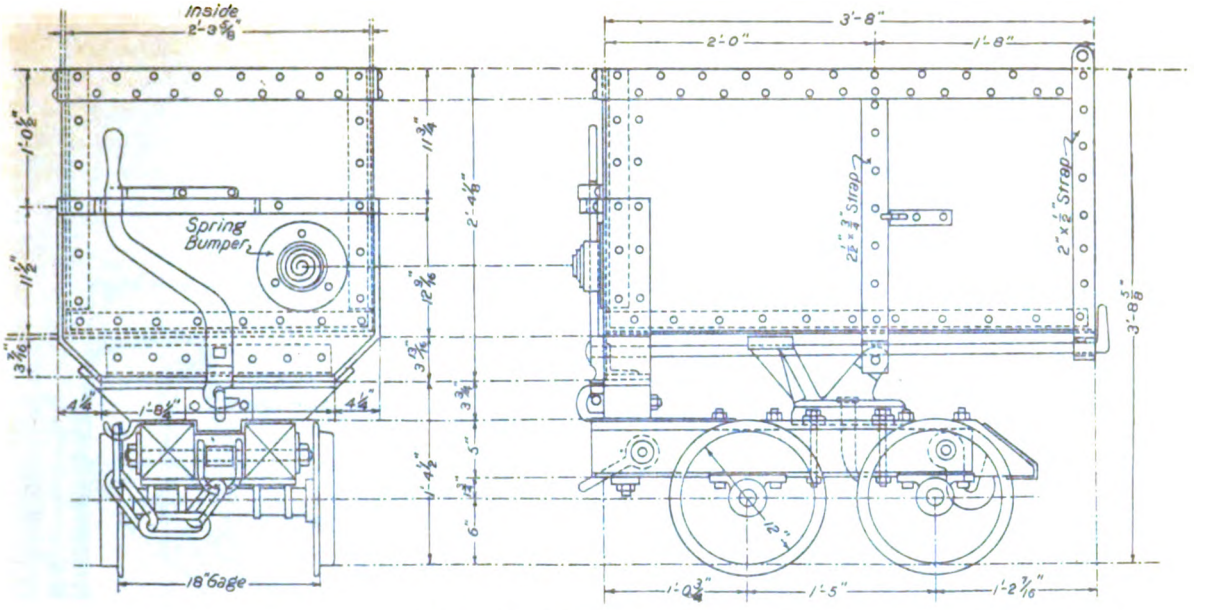

Figure 6.- 16½ cubic foot Mine Car.

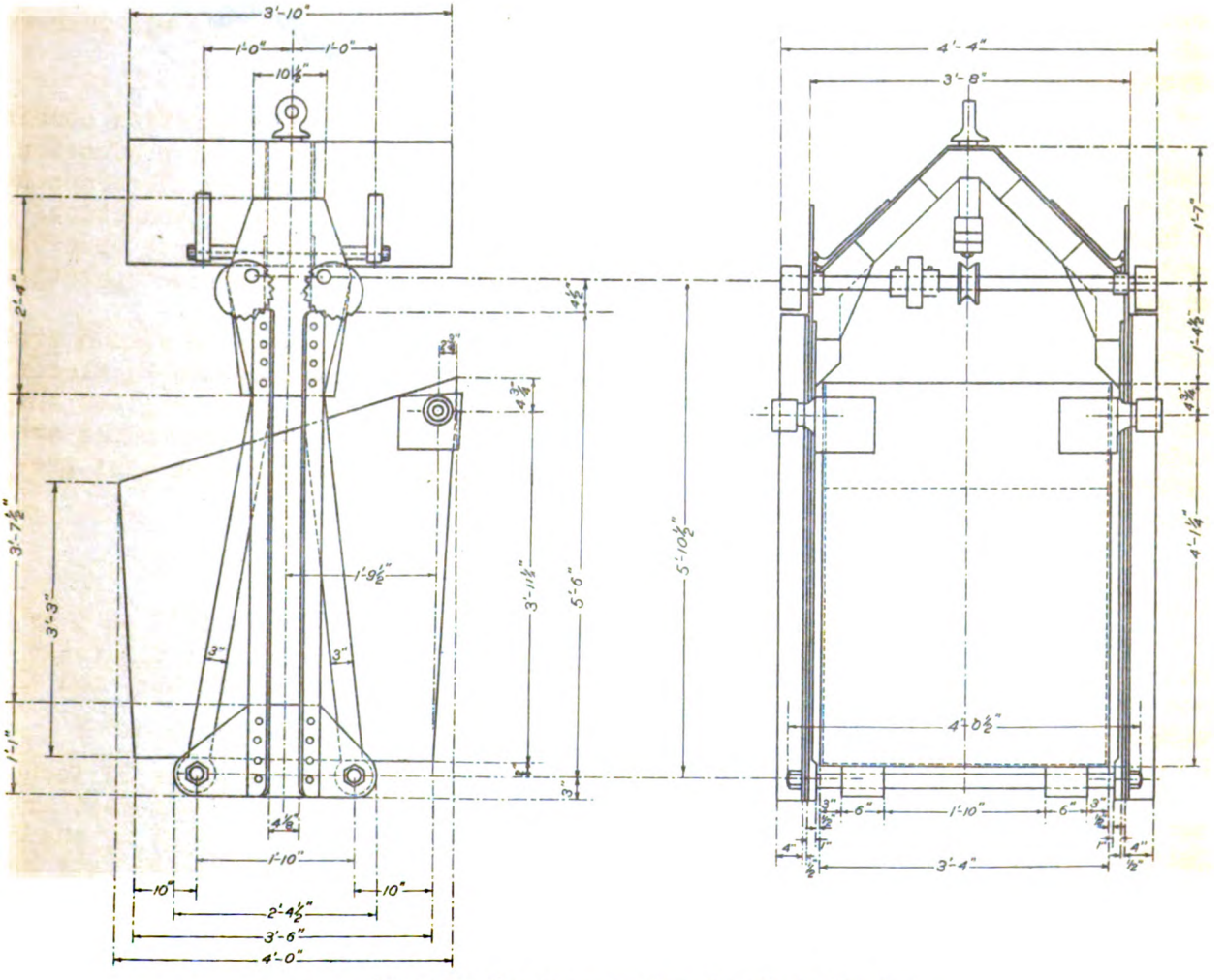

Figure 7.- General assembly of 44 Cu.ft. Mine Skip.

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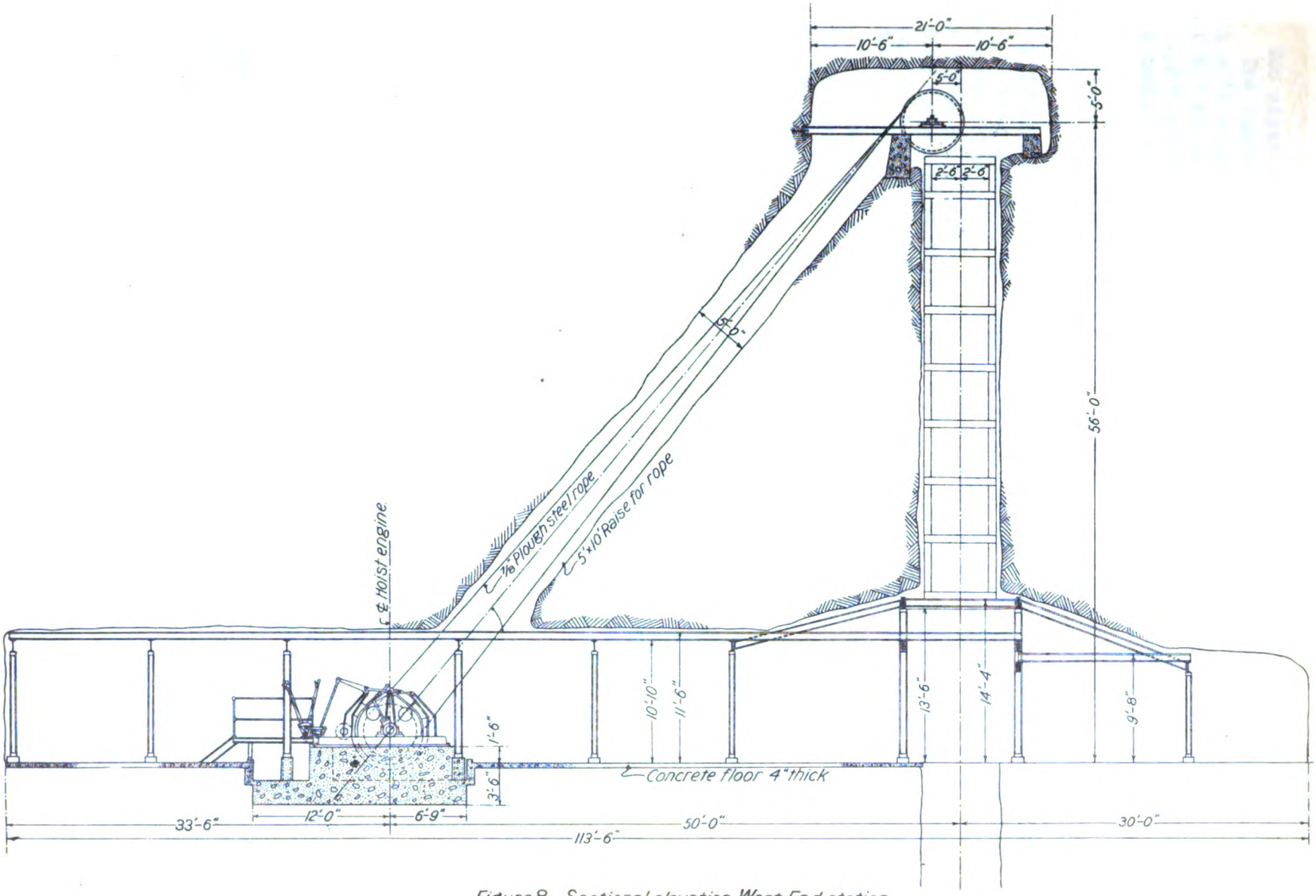

Figure 8.- Sectional elevation West End station.

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Two sizes of trolley locomotives are used for ore haulage on the main levels. The larger weighs 4.0 tons and has a draw-bar pull of 2,600 pounds. It is equipped with steel-tired wheels and two 250-volt ball-bearing motors, and has a speed of 4.7 miles per hour. The smaller locomotive weighs 3 tons, has a draw-bar pull of 1,200 pounds, and a speed of 5.2 miles per hour on level track. About 35 cars are hauled in a train. The average haul to the Silver King shaft is about 2 miles.

HOISTING

A 250-horsepower Corliss-type steam-operated hoisting engine serves the main Silver King shaft. Flat ropes are used on the winding reels. Each of the two reels is controlled by a clutch and can be operated independently of the other. The flat ropes are 3/8 inch by 6 inches, and are made of 18 strands of cast-steel wire. Each strand is made up of four smaller strands of seven wires of No. 16 size. The strands alternate right and left and are laced together with No. 16 soft iron wire. Double-deck cages, each weighing 2,400 pounds, are operated in counterbalance. The cars are secured in position on the cages by means of hooks, which fasten to eyes attached to each side of the car. Landing chairs are used on all levels of the shaft.

The Silver Hill hoist is a double reel, electrically driven, 400-horsepower type. Each reel has an outside diameter of 10 feet and an inside diameter of $3\frac{1}{2}$ feet, with a capacity of 2,000 feet of 3/8 by $4\frac{1}{2}$ inch flat rope. The motor generator set takes current at 2,200 volts, 60 cycles with a rated continuous input of 250 kilovolt-amperes. The generator is a computating pole, 600-volt, direct-current type of 165-kilowatt capacity. The skip has a capacity of 52 cubic feet and holds about 3 tons. It is provided with valves in the bottom so that water can be emptied when necessary. A cage is hung below the skip for transporting men and supplies. The skip is loaded from ore pockets and dumped into two timber bins with a capacity of 75 tons each.

The engine room at the Silver Hill station is excavated in solid rock. It is 110 feet in length with a span of 35 feet. Walls and roof are of concrete 2 to 5 feet thick and reinforced with steel rails and iron beams. The room has an elliptical roof, which raises from a minimum height in the back of $12\frac{1}{2}$ feet to a maximum height of 50 feet over the head frame. No support other than that of the concrete and reinforcing steel has been supplied.

The West End shaft is equipped with a 125-horsepower double-drum electric hoist and a skip (fig. 7) of 44 cubic feet or $2\frac{1}{2}$ tons capacity. A cage is hung underneath the skip for the carrying of men and supplies. The station cavity (fig. 8) is supported by steel beams and gunited to prevent slacking of the limestone. All of the ore bins in this shaft are equipped with discarded air drills to apply vibration to the bottom of the bins, thus to dislodge the ore when loading the skip. Figure 9 shows the small skip used in winzes.

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TRAMWAY

Concentrates and crude ore from the Silver King Coalition mill and mine are transported to Park City by an aerial tramway of Leschen type, 7,200 feet long. The difference in elevation between the lower terminal on the railroad at Park City and the upper terminal at the mine is 1,100 feet. The weight of ore going down is sufficient to transport coal and supplies from the railroad to the mine without additional power.

SAMPLING

The Silver King Coalition Mines Co. maintains its own sampling plant. All ores sold to the smelting companies are sampled, and determinations of the metallic contents, moisture, and tonnage are made before shipments are consigned to the smelter.

WAGE AND CONTRACT SYSTEM

About 80 per cent of the underground labor is American, 10 per cent Irish, and the remaining 10 per cent of various European nationalities. The following is the wage scale at the Silver King mine of May, 1930, for the principle classification of underground employees:

Cager	$ 5.00
Hoist engineer	5.75
Miner	4.50
Motorman	4.50
Motorman helper	4.25
Mucker	4.25
Machineman	4.75
Nipper	4.50
Pipeman	4.50
Pipeman helper	4.25
Powderman	4.50
Pumpman	4.25 and 4.50
Shiftboss	6.50
Timberman	4.75
Timberman helper	4.25
Trammer	4.25
Trackman	4.50 and 4.75
Trackman helper	4.25 and 4.50

All mining of ore is done by day labor. Many factors enter into the production of ore, among them being the size of the stope, the amount of refilling, sorting of waste, distance from the chutes, and dilution of ore. Because of these conditions, mining of ore on a contract basis is unsatisfactory.

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With few exceptions, all drifts, raises, and winzes are contracted for at prices varying from $4 to $11 a foot for breaking and shoveling. Terms are governed by the size of the heading and the condition of ground.

The mine is worked on the basis of two 8-hour shifts for all employees, excepting for underground compressormen, engineers, pumpmen, cage riders, who work three 8-hour shifts daily.

VENTILATION

Due to the large number of connections between levels and the number of openings to the surface at various elevations, the mine is well ventilated by natural air currents. When opening up a new level where only one connection has been made with the level above and the natural ventilation is not sufficient, air is then forced into the dead ends by means of small fans directly connected to motors.

SURFACE PLANT

The Silver King Coalition property is equipped with a flotation concentrating mill of 800 tons capacity daily, a sampling mill of 500 tons capacity daily and three modern change rooms; one at the collar of the Silver King shaft, one at the portal of the Alliance tunnel, and the third at the portal of the Silver King Consolidated tunnel. There are also blacksmith, carpenter, and machine shops, a mine supply store room, and a boarding house with sleeping quarters for 250 men. The company maintains and operates its own grocery store, coal yard, and boarding house for the benefit of its employees. No profit is made from this service. All timber is framed on the ground. Cars, cages, and other equipment are constructed in the machine shops, where all repairs are made. The property maintains its own engineering staff as well as electrical and mechanical organizations.

PRODUCTION

With the exception of a very small tonnage of crude ore, the entire output from the mine is treated in the company's flotation concentrating mill. Two products are made: One a high-grade lead-silver product with small zinc values and the other a zinc concentrate carrying a high zinc content and minor values in silver and lead. In 1929, the Silver King Coalition Mines Co. produced a total of 180,300 dry tons of ore. Of this amount, 92 dry tons was lease ore, and 219 dry tons was first class or crude smelting ore. The remaining 179,989 tons of second class or milling ore was treated in the flotation mill and 34,542 tons of lead concentrates and 14,642 tons of zinc concentrates were produced. The average metal content was as follows:

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Average metal content

	Lead (per cent)	Silver ounce	Gold, ounce	Copper	Zinc
Crude first class ore ...	42.31	58.53	.0448	1.56	7.98
Lead concentrates	62.495	80.97	.0936	2.45	6.9
Zinc concentrates	3.15	12.11	.0164	.50	54.75
Lease ore	45.28	67.02	.1564	.77	2.9

Table 1.--Summary of costs

Name of mine - Silver King Coalition Mines Co. Period covered - Year 1929

Tons of ore hoisted during period - 180,208.460 (Does not include lease ore).

Mining method - Stringer sets, stulls and filling.

Underground costs per ton of ore hoisted

	Labor	Super-vision	Compressed-air drills and steel	Power cost	Explo-sives	Timber	Other supplies	Total
Development in ore and in rock	1.210	.073	.382	.004[1]	.313	.091	.013	2.086
Mining	2.454	.130	.472	- -	.173	.249	.024	3.502
Transportation.	1.412	- -	- -	.299	- -	- -	.137	1.848
General underground expense	- -	- -	- -	- -	- -	- -	- -	- -
Surface expense (directly applicable to underground operation)...	- -	- -	- -	- -	- -	- -	- -	- -
Drainage	.139	- -	- -	.067	- -	- -	.103	.309
Total	5.215	.203	.854	.370	.486	.340	.277	7.745

Note: Transportation includes all local hoisting from underground shafts and winzes and general hoisting in the main shaft to surface, also trackmen and liability insurance.

1 Ventilation.

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Table 2.--Summary of costs in units of labor, power, and supplies

	Development	Mining (stoping)	Total
A. Labor (man-hours per ton):			
Breaking (drilling and blasting)	.709	.934	1.643
Timbering	.216	.683	.899
Shoveling and sorting	.764	2.154	2.918
Haulage and hoisting	- -	- -	2.239
Supervision	.008	.014	.022
General, includes some shop labor.	.199	.135	.334
Total labor underground	1.896	3.920	8.055
Average tons per man per shift	4.219	2.041	.993
B. Power and supplies:			
Explosives (gelatin) pounds per ton	(50%)	(35%)	3.607
Timber, for year	$16,463.76	$44,822.61	$61,286.37
Electric power used at mine, kw.h.			14,006,750
Per ton ore, kw.h.			77.7

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Table 3.--Detail of costs in units of labor, power, and supplies

Development

	Sinking	Drifts and crosscuts			Raising	Total all development
Linear feet of excavation	486	22,333	5,483	1,809	2,994	33,105
Size of excavation	1 and 2 compartments	5 x 8	6 x 8	6 x 8	1, 2 and 3 compartment	
Physical properties of rock	Med. hard	Med. hard	Med. hard	Med. hard	Med. hard	
A. Labor (man-hours per foot):						
Breaking (drilling and blasting)						3.864
Timbering						1.121
Shoveling						4.159
Haulage and hoisting						5.629
Supervision						.430
Total labor						15.203
Feet per 8-hour shift						.526
B. Power and supplies (per foot):						
Explosives (cost per foot)						$ 1.706
Timber (cost per foot)						.497
Total power						
Air compression (cost per foot)						.440
Hoisting (cost per foot)						- -
Haulage (cost per foot)						- -
Ventilation (cost per foot)						.023
Other supplies						1.037

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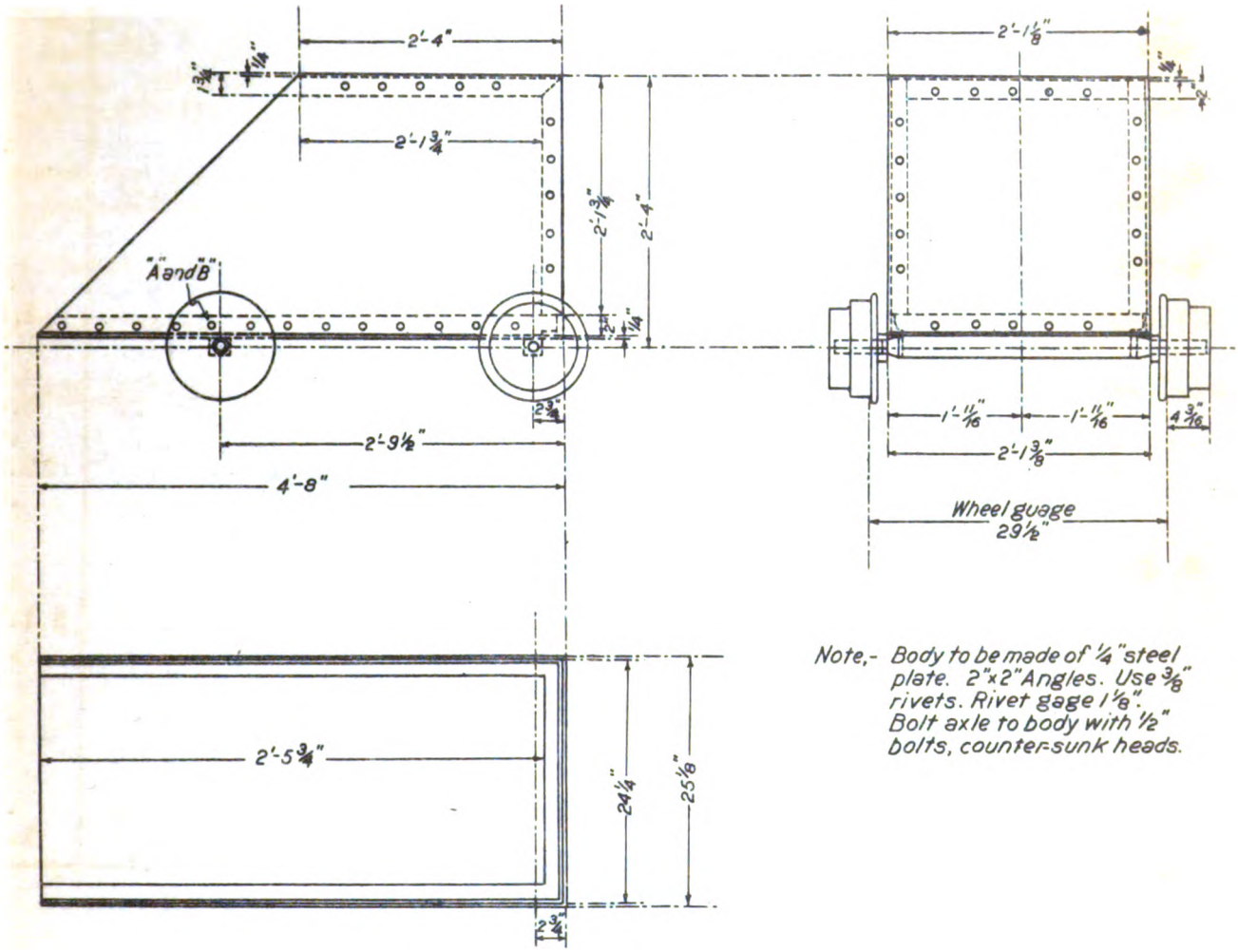

Figure 9.- Assembly of Skip body.

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